Computational Fluid Dynamics Study of Abrupt Wing Stall on an F/A-18E Using The ARL Job Migration Tool

Presented by

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Presentation Outline

- Introduction to the Job Migration Tool
- User Scripting, Setup, and Execution
- Testing and Portability
- User Interaction and Comments
- CFD Test cases and the Abrupt Wing Stall
- CFD Program Objectives
- F/A-18E CFD Model Description and Flow Solver
- Probable Root Cause of the F/A-18E/F AWS Phenomena
- Conclusion

Introduction to the JMT

- The JMT enables user's to run single computations as a sequence of jobs that toggles back and forth between two respective computer sites

- Automatically handles halting the processing at one site, then transfers all necessary files to the another host machine and resumes execution

- Consists of a pair of scripts (Pilot & Work) which the user does not have to customize:
  - The JMT is invoked by simply submitting the JMT pilot script to the queuing system

- Currently works with the Global Resource Director (GRD) queuing system

User Scripting, Setup, and Execution

- **User copies six sample files from Master set, customizes them, and executes them.** **(5 scripts, 1 configuration file)**
- **Five scripts specify the commands for:**
  - **Pre-processing (example: grid generation)**
  - **Execution**
  - **Halting execution gracefully (cycle counting)**
  - **Tarring intermediate files**
  - **Post-processing (for example, plotting)**
  - **One configuration file for:**
  - **Lists machine and job specifics such as:**
    - **Name and location of run, scratch, output, & tmp directories**
    - **Number of processors and how long to run**
    - **What site to start job, etc…**
- **Execution:** **(as an example)**
  - **Just type: qsub –l arl /usr/grd/local/bin/JMT/pilot**

Testing and Portability

- **Built and Tested using the WIND CFD flow solver**
- **Tested on SGI O2K's between PAX DC and ARL MSRC**
- **Two fully converged CFD solutions obtained**
  - **Ran on 24 CPU's alternatively (12 hours each box)**
  - **With JMT ~9 days needed per solution**
  - **Without JMT ~18 days needed per solution**
- **Designed with an open architecture in mind to allow portability to other CFD codes and Computational platforms**

User Interaction and Comments

- **Very easy to set up and use**
- **One problem encountered was that the GRD queues were disabled, putting the job on hold. Once the queues were enabled, the job continued execution without a glitch**
- **Ability to use all possible resources, maximizing job turn-around time**
- **Primary benefit was time to complete job was cut in half**
- **Possible Future Capability:**
  - **Ability to run jobs at other MSRC's that might have available resources (search and seek)**

CFD Test Cases and the Abrupt Wing Stall

- Tested on existing F/A-18E geometry for the Abrupt Wing Stall (AWS) Program using the WIND CFD flow solver
- Two converged solutions obtained using the ARL JMT
- On average, one solution took ~5000-6000 CPU hours to fully converge

Historical Background

- In 1997 during the EMD phase of the F/A-18E/F program, the aircraft experienced severe wing drops during target tracking maneuvers at or just below transonic speeds. Wing drop results from asymmetric flow separation on the wing upper surface and produces high roll rates and large bank angles. It has been experienced before on other fighter designs. Although a solution, which consisted of using a porous surface at the wing fold, was found and demonstrated to work in flight, little knowledge of the root cause of this phenomenon was developed. At the request of the Blue Ribbon Panel, the OSD called for a national program to develop a comprehensive understanding of the phenomena causing transonic AWS, and to develop the analytical and experimental tools to avoid it in future aircraft.

- The AWS program was formed and sponsored by ONR and NASA LaRC and is supported by the Navy, NASA, Industry, and Universities

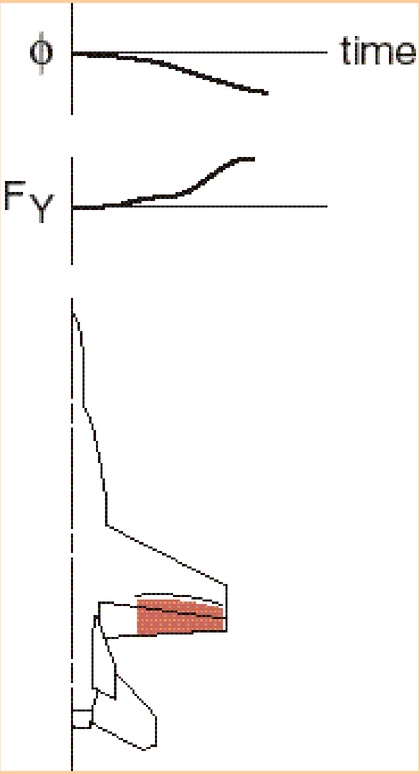
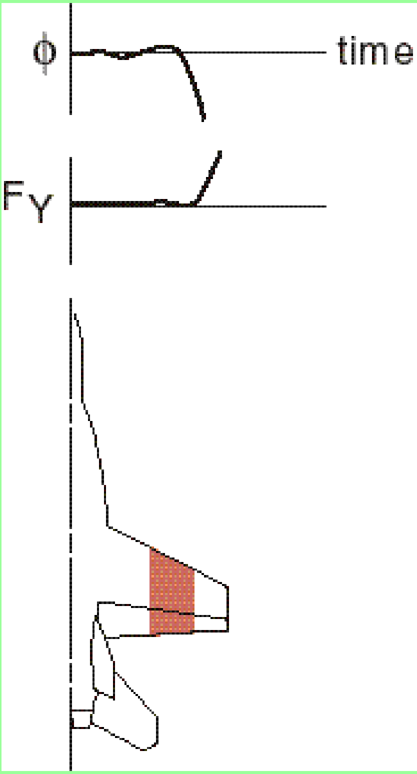
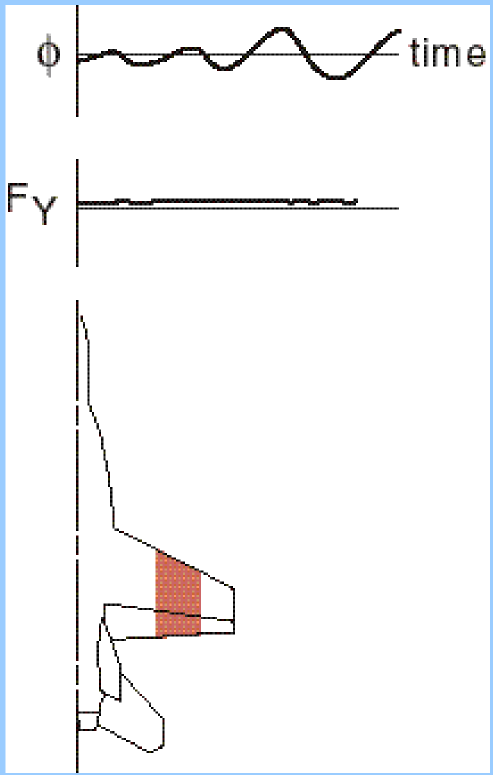
What is an Abrupt Wing Stall for an Aircraft ?

- **Primarily applicable to fighter type aircraft, an Abrupt Wing Stall (AWS), also known as "Wing Drop", is an uncommanded, irregular, and non-periodic lateral motion of an aircraft caused by asymmetric wing stall (typically at transonic speeds). If severe, wing drop can result in sudden large roll attitude changes of 60° or more. If operating at low altitudes, this could result in the loss of the vehicle.**

Flight tests:

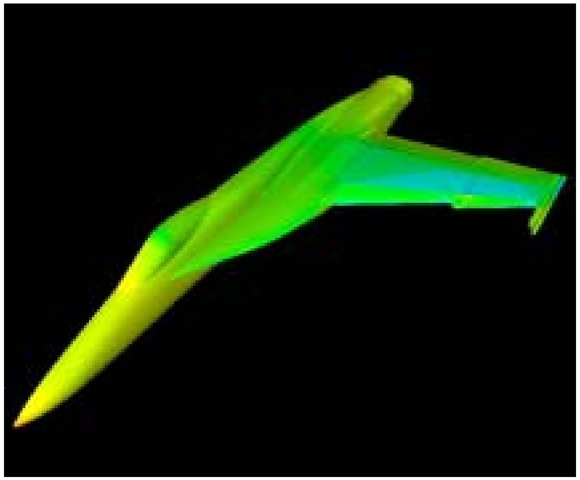
- ~1.5 years of developmental flight testing and evaluation
- 100^{+} configurations, 500^{+} flights, $9{,}000^{+}$ windup turns

Terminology

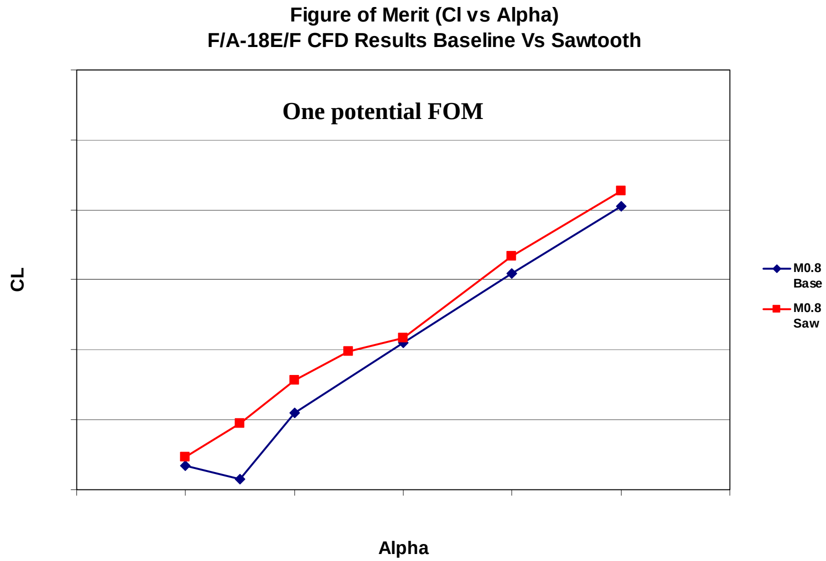
Heavy Wing	Wing Drop	Wing Rock
		
• Shock-induced T.E. separation • “Out of trim” event	• Many mechanisms at speeds of interest • Abrupt roll off	• Many mechanisms at speeds of interest • Periodic dynamic events • Limit-cycle phenomena

Role of CFD

Computational Fluid Dynamics is being used to compute aerodynamic characteristics of the complex flow on and around the F/A-18E aircraft, providing insight into the Abrupt Wing Stall phenomena.



Baseline F/A-18E CFD surface grid with pressure coefficients

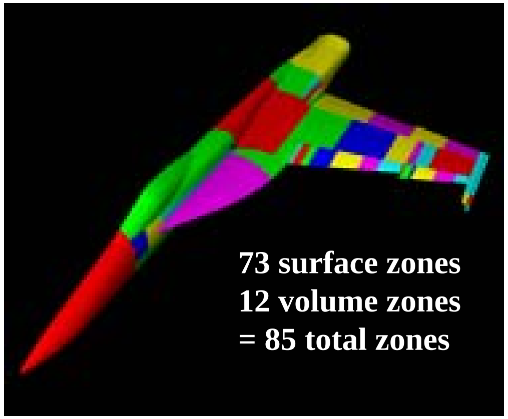


CFD Objectives

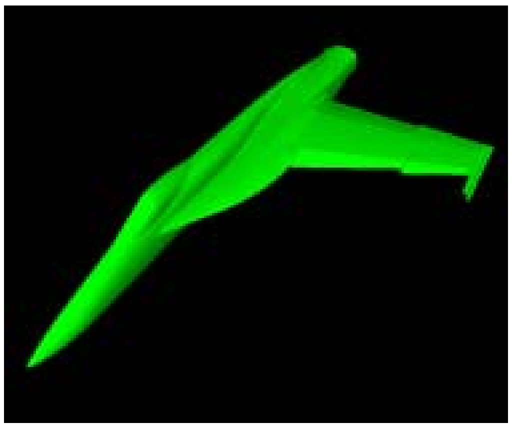
- **CFD Code Validation**
- **Help to gain a better understanding of the AWS phenomena**
- **Develop Figures Of Merit (FOM's) through better understanding**
- **Develop analysis/design guidelines for future aircraft designers to reduce or eliminate an aircrafts' susceptibility to Abrupt Wing Stall**

The F/A-18E CFD Model

Baseline 10/10/5

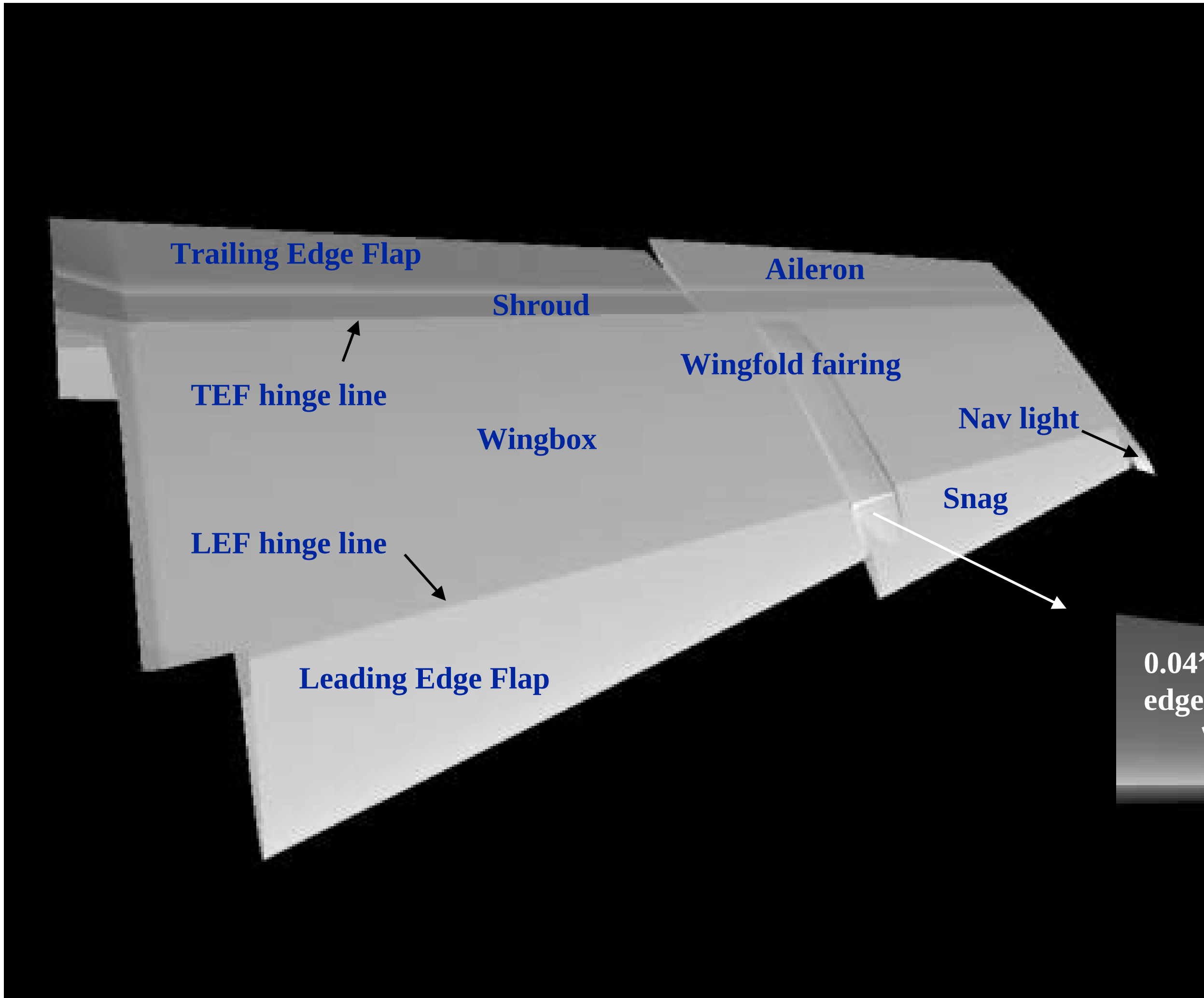


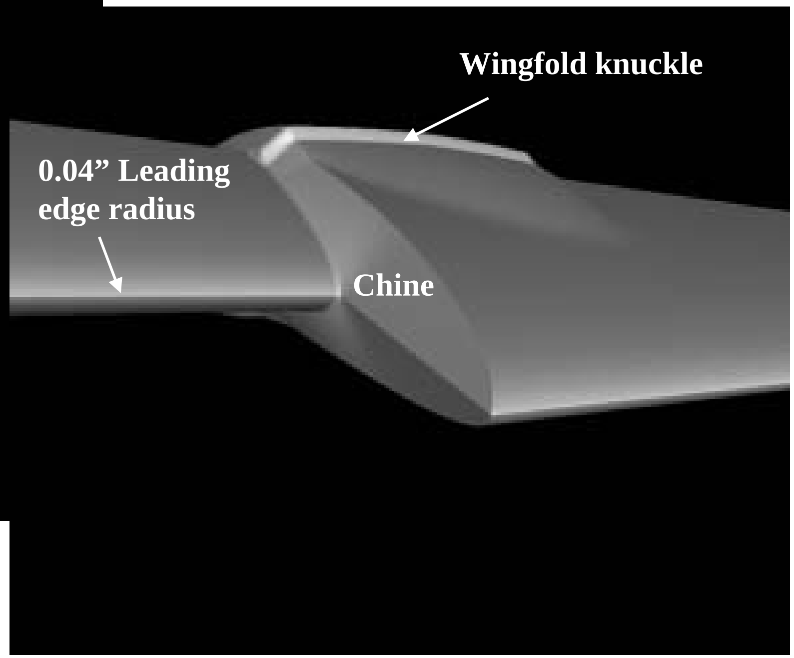
Merged surfaces for visualization only



- **Grid Model**
  - Half body, nacelle, and wing (no vert. & horz. tails)
  - Clean wing with missile (no fins)
  - 10/10/5 flaps (LEF,TEF,Aileron)
  - From 5.6 million → 13 million points
  - Model ran at 8% scale to match Calspan WT test data
  - Re # = 3.0e6/ft
- **Grid topology**
  - Mostly Block-to-block with some chimera topologies
- **Calculations with WIND (former NASTD) V1.13**
  - Steady State Solutions
  - Used Reynolds Averaged Navier-Stokes Equations
  - Turbulence model:
    - Menter Shear Stress Transport model (SST)
  - Average CPU wall clock time to get converged solution was 5760 hrs. (24 cpu's/day for 10days)

Wing Geometry Definition

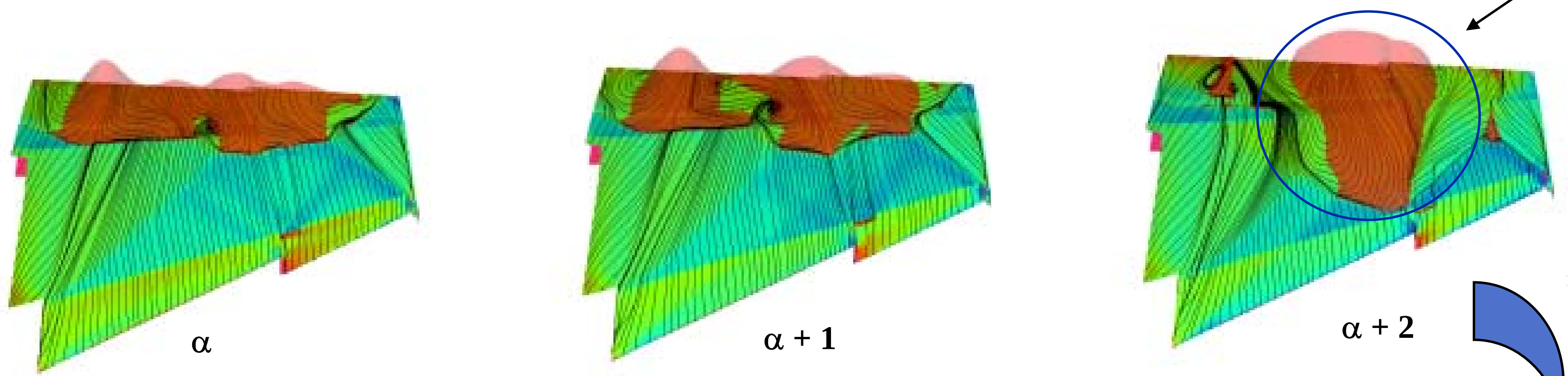




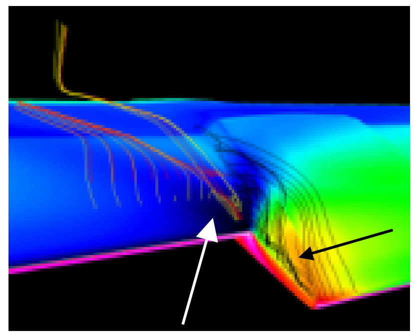
Complexity of the Problem

Baseline 10/10/5 flaps, Mach 0.9, Re=3e6

Abrupt separation over
mid-span in 1° change of AoA



Baseline 6/8/4 flaps



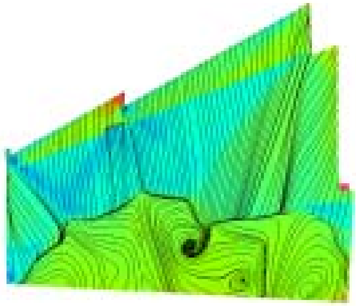
Snag vortex

LEF separation
just inboard of snag

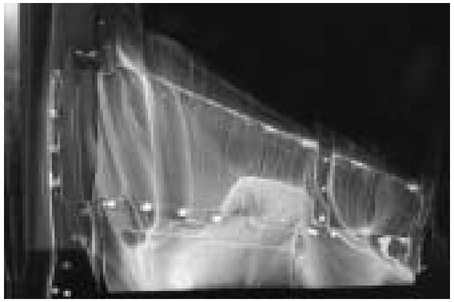
- **Complex 3-D shock/boundary layer interactions**
- **Unsteady flow**
- **Many possible flow separation mechanisms**
  - **Trailing edge flap separation**
  - **Leading edge flap separation**
  - **Shock induced separation**
- **Reynolds number effects (WT, Flight,CFD)**
- **A combination of one, two, or all the effects mentioned above**

CFD Code Validation

Baseline 10/10/5, Mach 0.9, Re=3.0e6/ft

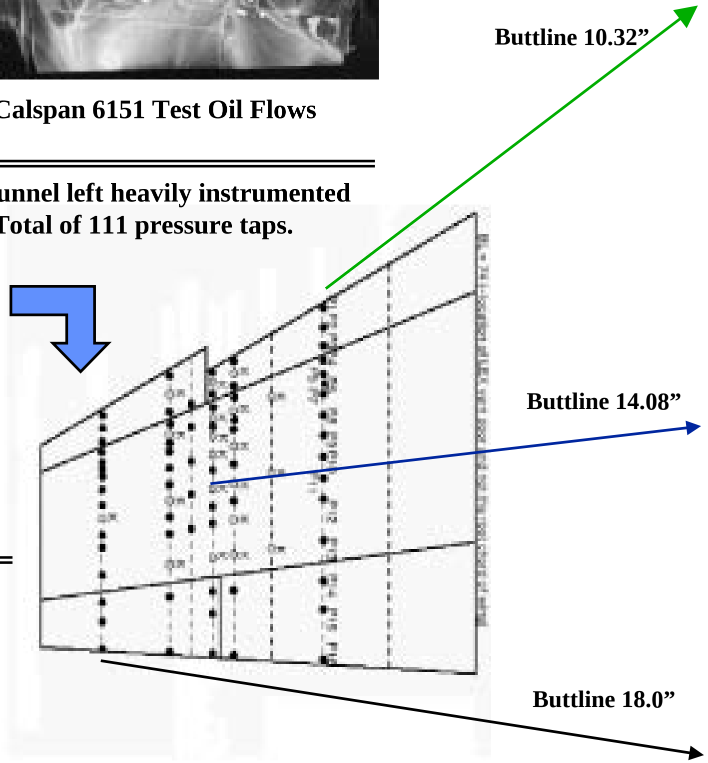


WIND CFD Result



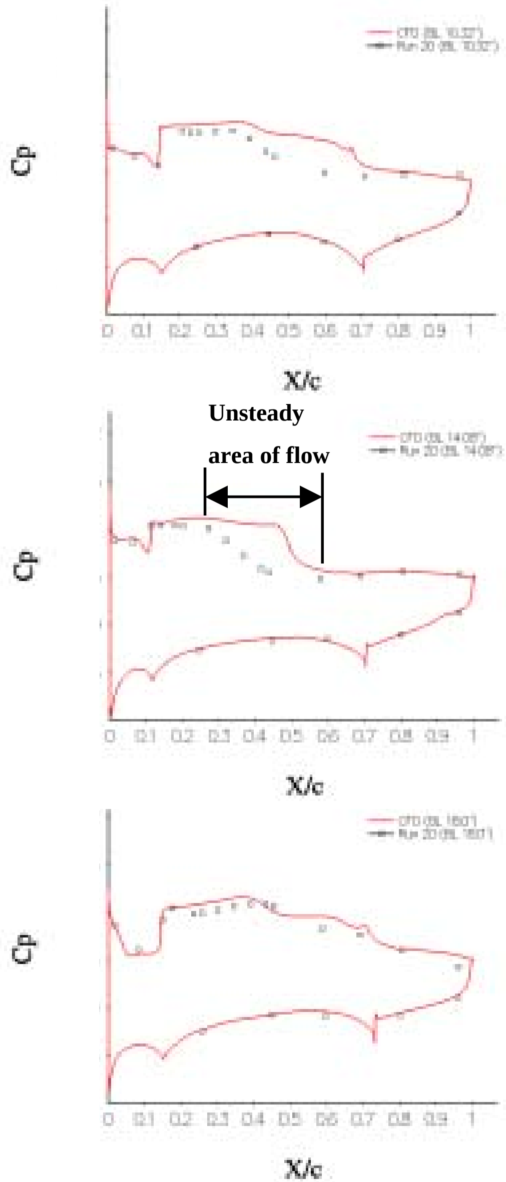
Calspan 6151 Test Oil Flows

Wind tunnel left heavily instrumented wing. Total of 111 pressure taps.



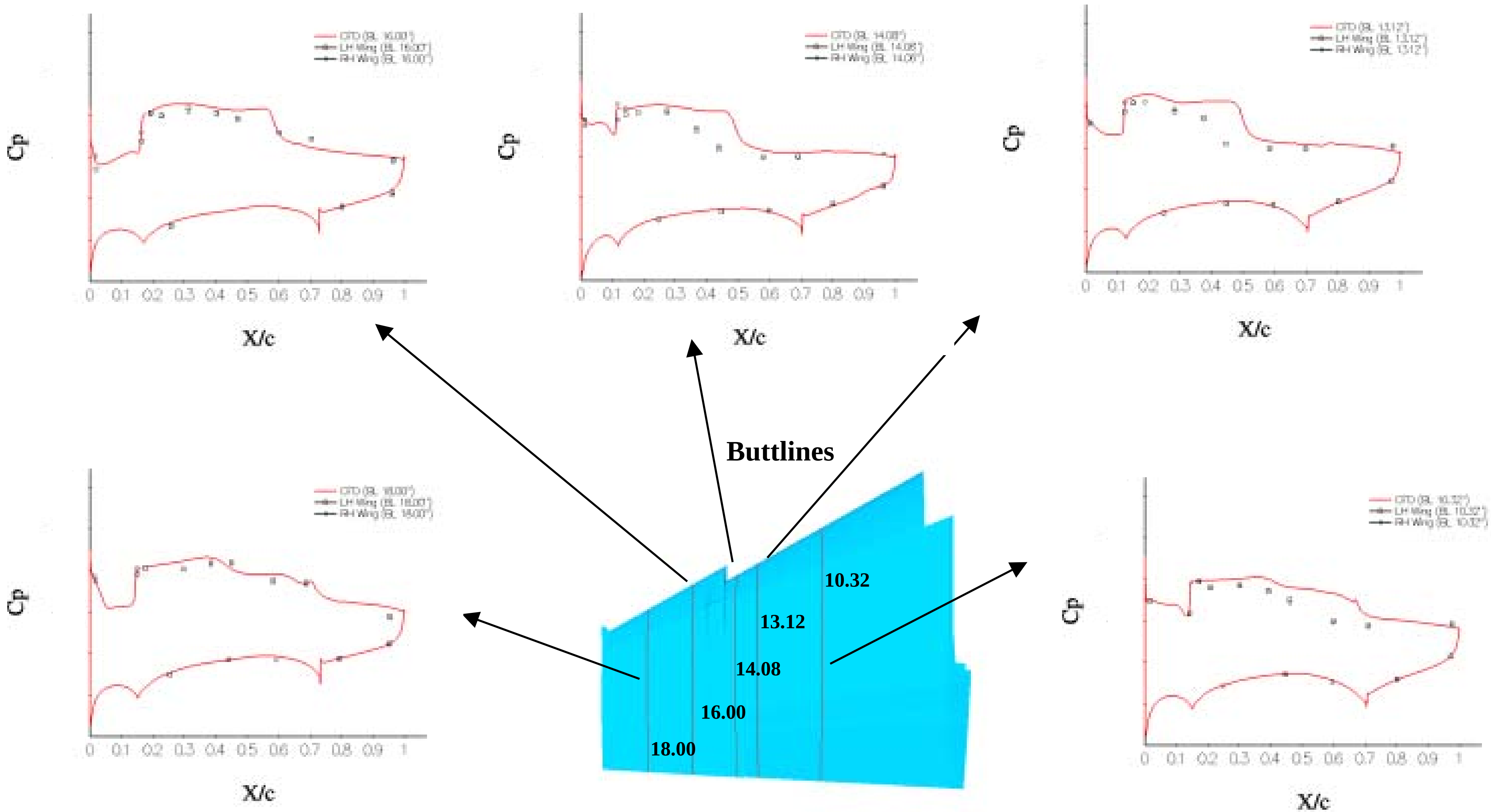
Some flight tests flown with limited instrumented wing. (Approx. 30 pressure taps)

Baseline 10/10/5, Mach 0.9, Re=3.0e6/ft

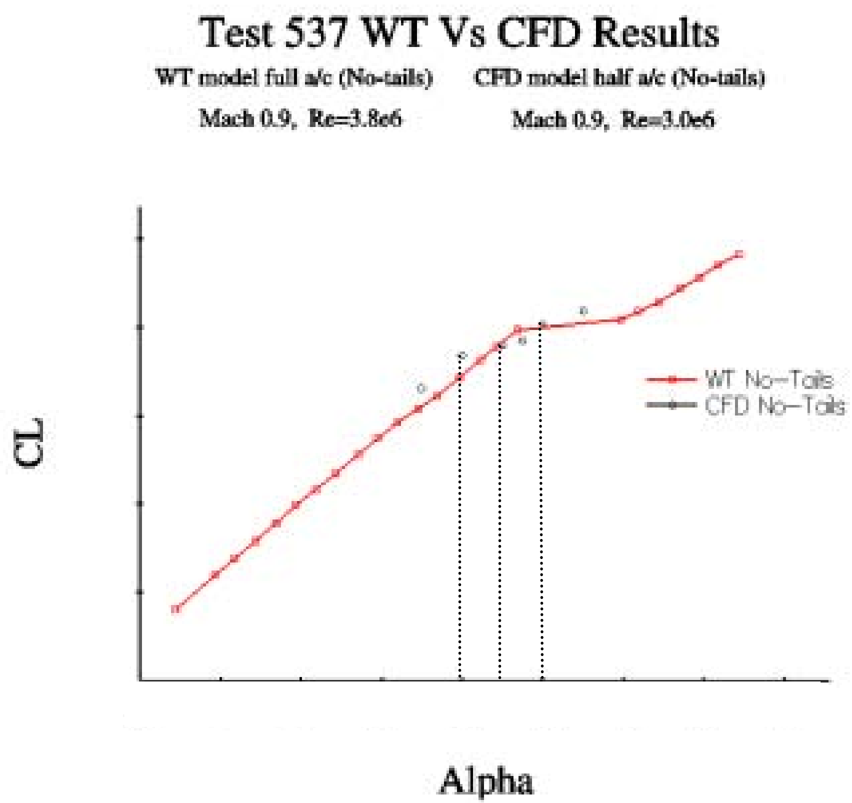


Cp Vs X/c Comparisons

Baseline F/A-18E, Mach 0.9, 10/10/5 Flaps, Re=3.0e6/ft



Comparison of WT and CFD Flow Visualization for Mach 0.9

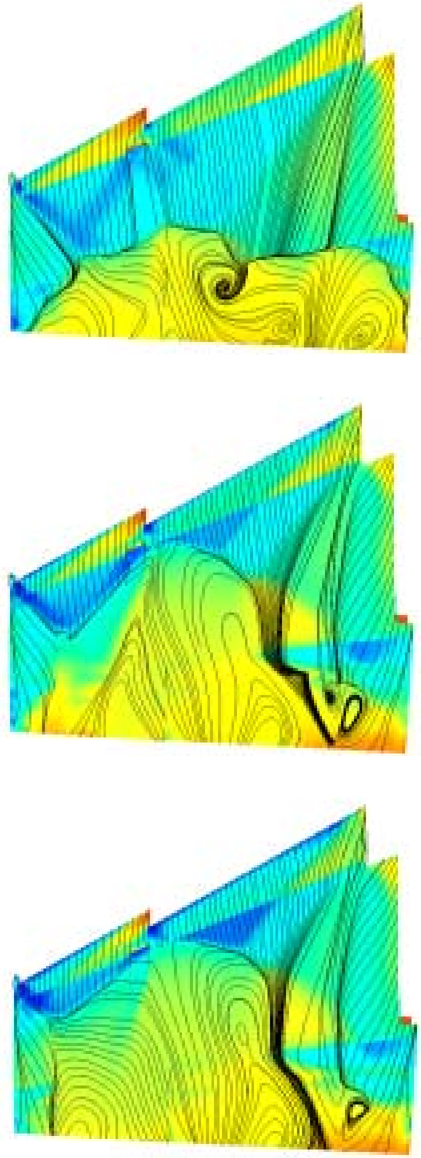


Data with tails

α

α +1

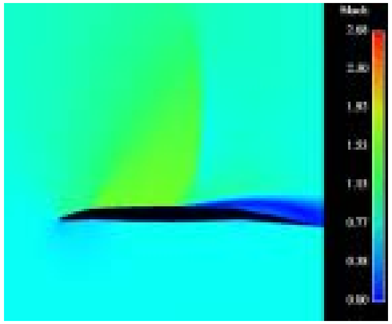
α +2



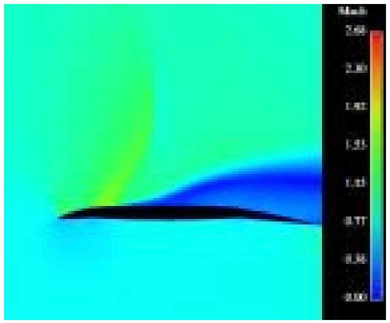
F/A-18E/F Progı

CFD Analysis for Better Understanding

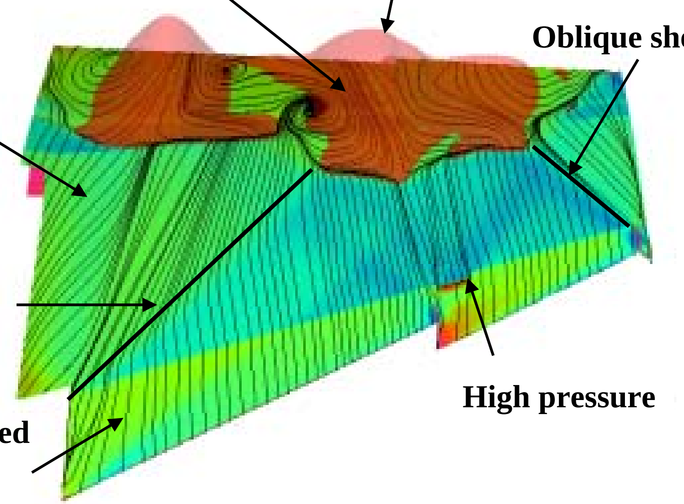
α Baseline Buttline 14.08”



α+1 Baseline Buttline 14.08”



2D Mach contours showing advancement of shock induced separation from 60% x/c to 20% x/c in a 1° AoA change.

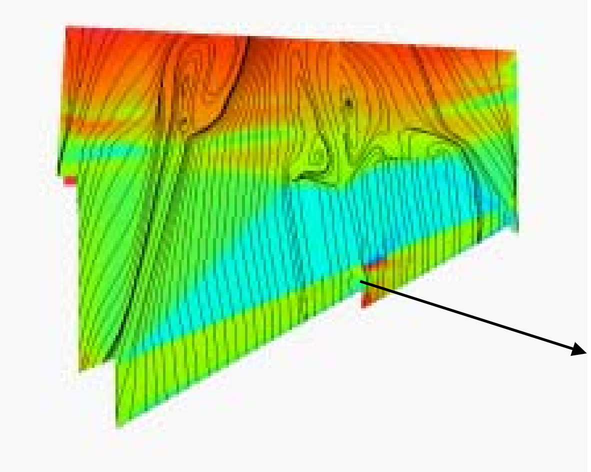


Baseline 10/10/5, Mach 0.9, Re=3.0e6/ft

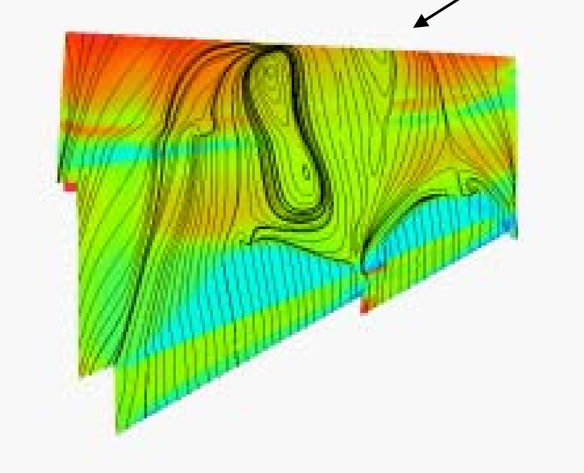
Probable Root Cause of the AWS

Baseline 10/10/5, M0.9, Re=3e6/ft

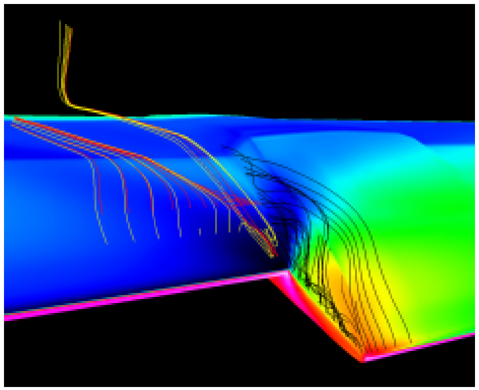
α



α + 1

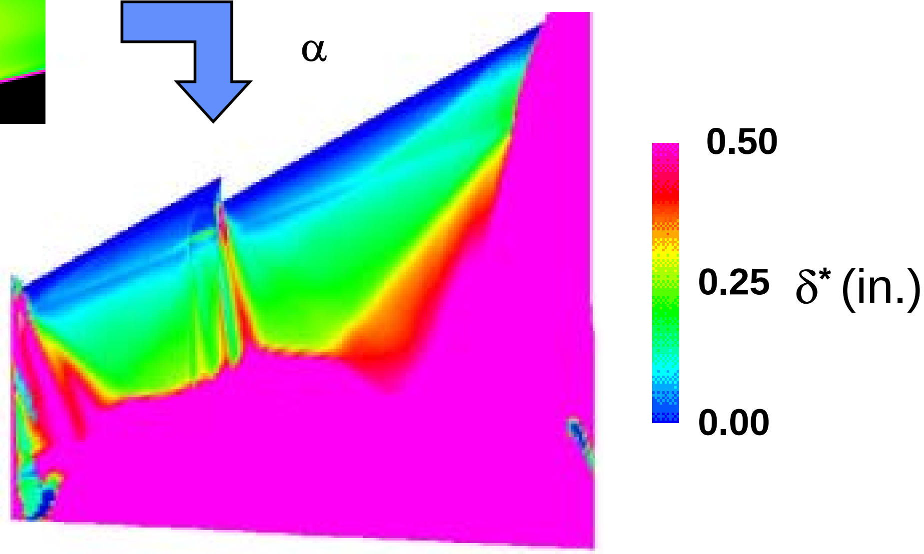


Baseline Snag

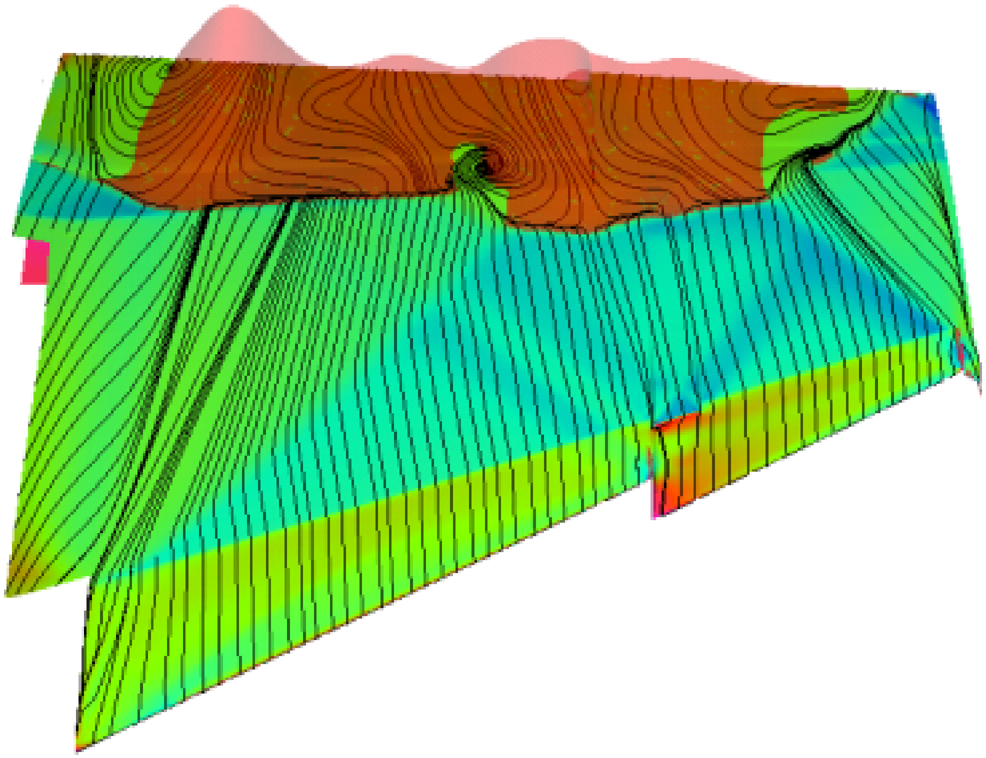


α

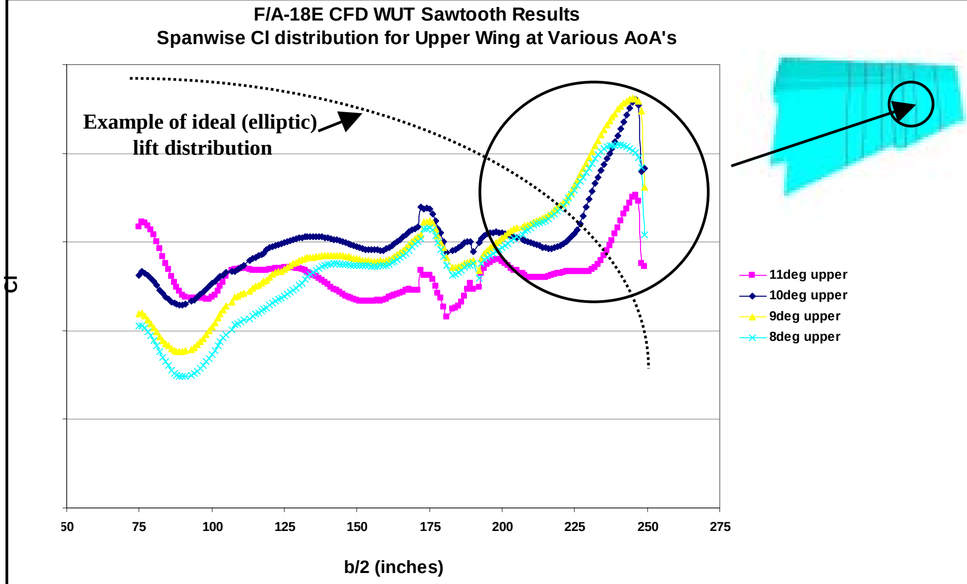
Contours Of Boundary Layer Displacement Thickness

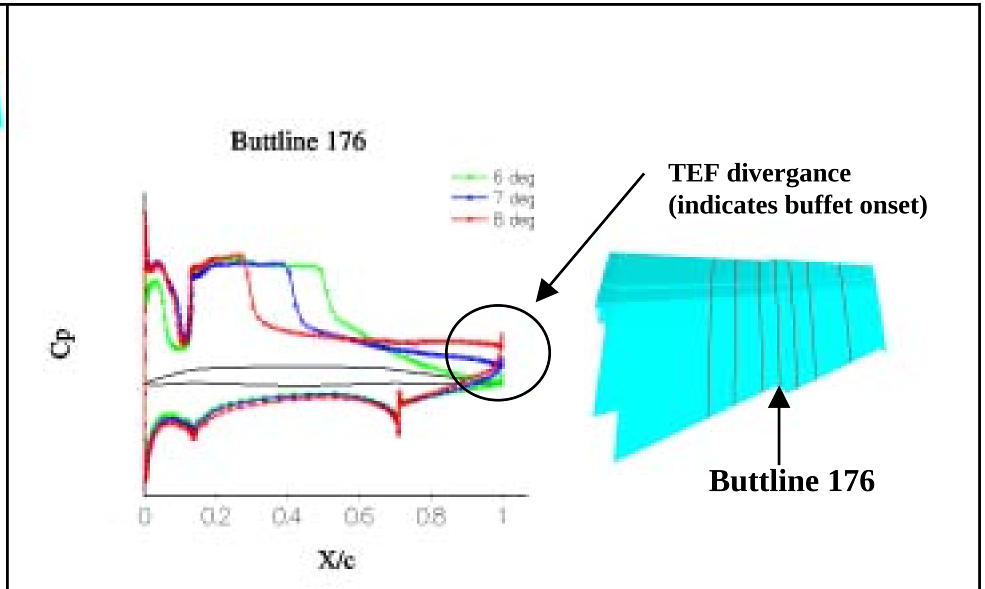


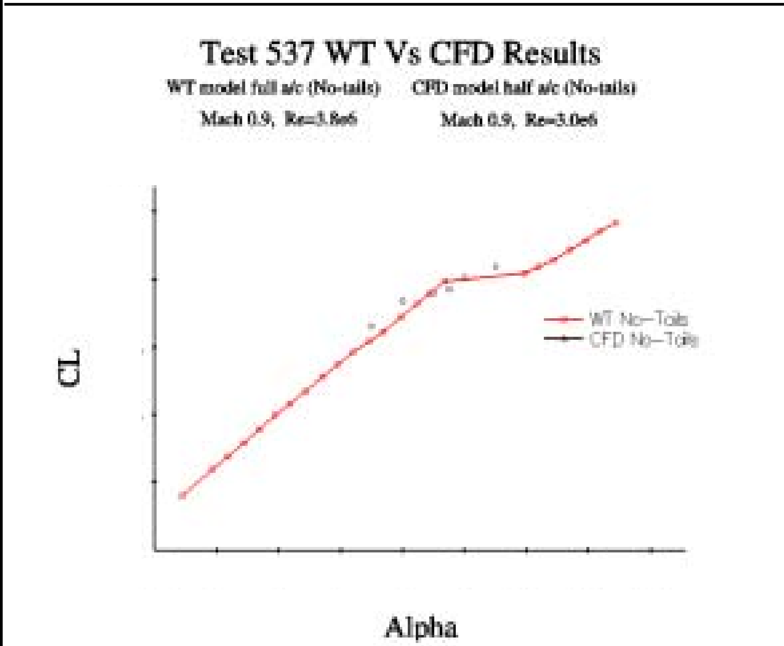
Movie of Separation as AoA is Increases

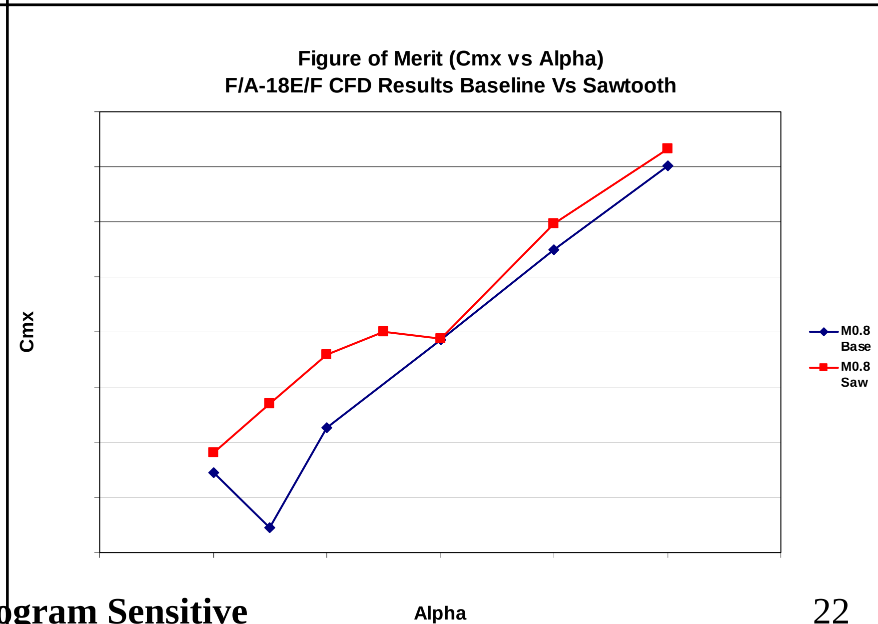


Figures Of Merit & Design Guidelines









Conclusions

- The ARL JMT was very useful in allowing the maximum use of computational resources between ARL and NAWCAD DC
- Time to compute one solution was cut in half
- The ARL JMT tool is easy to setup and can be used with other CFD codes and computational platforms
- A better understanding of the AWS phenomena has been learned through use of the JMT
  - Primary cause for F/A-18E/F is a LEF separation just inboard of snag
  - Secondary causes (applicable to all fighter type a/c) is:
    - Shock induced separation
    - 3D Oblique and Normal shock interactions
    - TEF separation
- The ARL JMT played a vital role in helping the AWS program achieve its CFD objectives, leading future aircraft design processes